



Complexifying the urban lawn improves heat mitigation and arthropod biodiversity

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ABSTRACT

Urban green infrastructures (GI) are important features of cities which provide many ecosystem services promoting citizens' well-being. As space is often limited in cities for establishing new GI, it is important to optimize the contribution of ecosystem services of existing GI. The objective of this paper is to compare the performance of lawns to three more complex types of recently established common low-height urban green infrastructures (LHGI) in relation to two ecosystem services: heat mitigation and habitat for biodiversity. We collected data from 48 plots in a semi-controlled context in the Greater Montreal area (Canada) where we compared unmanaged sowed indigenous herbaceous vegetation (flower meadow), medium-sized hedgerow (hedgerow), highly maintained lawn (lawn) and naturally regenerated unmanaged shrub vegetation (natural). We quantified the contribution of plant structure and species diversity to the two ecosystem services, using surface temperature and arthropods morphospecies richness as indicators of heat mitigation and habitat for biodiversity. We also tested the use of the Mean Information Gain (MIG) computed from photos, a measure of complexity, as a possible indicator of LHGI performance. There were major differences in both surface temperature and arthropod morphospecies richness between lawns and the other three LHGI. Results showed that plant structure and diversity improved LHGI performance. Finally, MIG was not found to be usable as good LHGI indicator in our experimental context. This study shows that increasing plant structural complexity and/or diversity increases heat mitigation and habitat for arthropod biodiversity of LHGI. Given its extent in North America, complexifying the omnipresent urban lawns holds considerable potential for GI improvement.

1. Introduction

Urban green infrastructures (GI), small and large, are important contributors to city functioning and citizen well-being. Their contribution lies in their use as city landscape elements and in their direct production of ecosystem services (ES) such as water management, urban heat mitigation, habitat for species, etc. (Haase et al., 2014; Kabisch et al., 2015). Individually, GI greatly vary in form, purpose, composition and structure (Lehmann et al., 2014).

The variation in GI is reflected in their performances as there are great discrepancies in the ES they supply (Mexia et al., 2018). In cities, space is limited and its potential use is often disputed among conflicting usages. Therefore, it is of great interest to assess the performance of different GI in relation to ES production for the optimal planning and

development of the city's overall GI assets. This planning can prioritize suboptimal areas and coordinate targeted actions to enhance such areas.

Given its omnipresence in urban areas, low-height green infrastructure (LHGI) offers an opportunity for GI development (Klaus, 2013). LHGI are all areas where vegetation height and density are low such as lawns, meadows, low shrubland, and hedges. They are often found as part of the backyard and front yard of houses and businesses, recreation areas and various vacant and unmanaged spaces. (Gaston et al., 2005b; Bonthoux et coll., 2013). LHGI occupies a significant relative area, e.g. from 22 % to 50 % of total city green space in the cases reported by Cameron et al. (2012). In the US, lawn, a typical LHGI, represents 8–16 million hectares, for an average ratio of house area to lawn between 55 % and 95 %, depending on neighborhoods (Robbins et al., 2001). In the Greater Montreal area, the LHGI area has been estimated at 68,000 ha,

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or 27 % of the total urban area (Francoeur et al., 2018).

Studies have shown that LHGI supply fewer ES per unit area in comparison to urban woodlands (Dupras et al., 2014; Mexia et al., 2018). Since LHGI is implemented or maintained where trees either do not fit the landowners/users' preferences or cannot be established due to constraints, e.g. lack of space (Ignatieva et al., 2015), assessing the performance among the different LHGI types could help guide landscaping choices where trees are not a preferred option (Mukherjee and Takara, 2018). Despite their role in urban ecological planning (Angold et al., 2006) and their potential for increasing GI performance (Aronson et al., 2017; Lovell and Taylor, 2013), LHGI were among the least understood green zones in urban ecosystems (Haines-Young et al., 2006; Cadenasso et al., 2007; Gaston et al., 2005a). However, recent evidence suggests that performance could be enhanced through simple vegetation interventions (Threlfall et al., 2017). Measures systematically targeted at optimizing supply through architectural and landscape design can significantly increase the supply of local-scale urban ES (Kremer et al., 2016). Complexifying oversimplified LHGI may thus contribute to provide a close match for ES demand and supply at local scale (Kremer et al., 2016).

Among the array of ES, urban heat mitigation (regulation ES) and providing habitat for biodiversity (provisioning ES) are good candidates for assessing important aspects of the LHGI performance for two reasons. First, they are of major relevance in the urban context (Norton et al., 2015; Albert et al., 2017; Nilon et al., 2017; see below), and second, they offer enough variation to allow for comparison among them at local scale.

Urban heat and its adverse effects on human health, comfort, and energy use is a major concern for city managers (Armson et al., 2012; Mavrogianni et al., 2011; Tan et al., 2010). This concern is growing in importance since frequency, intensity and duration of heat waves are expected worsen in the upcoming years due to climate change (Meehl, 2004). The ability of the vegetation to modify the local urban microclimate varies depending on plant composition (Gillner et al., 2015) and structure, such as canopy and leaf characteristics (Armson et al., 2012; Sanusi et al., 2017). Vegetation structure, measured by leaf angle, leaf size, canopy architecture or canopy density, has been shown to be the main urban heat mitigation driver for trees (Sanusi et al., 2017).

Habitat for species and biodiversity provisioning is an important service for conservation purposes (Rockström et al., 2009). Although the relation between biodiversity and ES supply is unclear and debated (Mace et al., 2012; Schwarz et al., 2017), biodiversity is more likely to be positively linked to ES supply (Ziter, 2016). Higher biodiversity is perceived as linked to overall ecosystem functioning (Philpott et al., 2014), even for species in low abundance (Violle et al., 2017). It is also taught to be associated with higher resilience, and thus services' persistence over time (Isbell et al., 2015; Oliver et al., 2015, but see Heilpern et al., 2018). At small scale, arthropod diversity and biomass is used as a legitimate indicator of habitat for species and other ES (Schwarz et al., 2017). Arthropods are important ES providers as they contribute to key services such as pollination, pest regulation, decomposition, refuse consumption, etc., (Lowenstein et al., 2014; Sugiura et al., 2013; Youngsteadt et al., 2015). Arthropods is also an important part of the urban trophic web and due to their omnipresence in UGI, they can thus serve as a useful indicator of LHGI performance.

A review on the factors promoting biodiversity in urban wasteland (Bonthoux et al., 2014) shows that, locally, the area size, age, soil, microclimate and vegetation structure are the dominant factors. Two other factors promoting biodiversity in LHGI such as golf or lawn include habitat heterogeneity (Hudson and Bird, 2009; Cornelis and Hermy, 2004; Norton et al., 2014; Shwartz et al., 2013) and maintenance of their elements (Politi Bertoncini et al., 2012; Chollet et al., 2018). Maintenance, such as mowing, was shown to impact plants, soil microbes and invertebrates (Norton et al., 2019).

Among the aforementioned factors, vegetation composition and structure, stand out as predominant drivers fostering both heat

mitigation and habitat for biodiversity. They also represent accessible and low-cost levers for LHGI intervention or maintenance strategy, but were only partially assessed, especially in North America. Using indicators is crucial in GI management because it allow ecosystem complexity to be condensed to a manageable level to inform decision and action (Haase et al., 2014). In that regard, there is a strong need to develop, empirically assess and broaden the knowledge on indicators in the urban context (Haase et al., 2014; Kremer et al., 2016). A promising index has been developed to describe the complexity of a plot using photographs (Proulx and Parrott, 2009). As this single index can potentially characterize rapidly and at very low cost any small-scale GI, it is of interest to assess its value as a performance indicator in the urban context.

This paper aim to partially address the lack of technical recommendation pointed out by Haase et al. (2014) at the understudied patch scale (Ziter, 2016) using simple indicators of performance. As the literature is still unclear whether ES are provided by the habitat type or community/structural processes (Ziter, 2016) a dual angle was adopted. Thus, the primary objective was to compare the performance of lawn to three more complex LHGI alternatives (unmanaged herbaceous vegetation, hedgerow, and naturally regenerated shrub vegetation) commonly found or implemented in urban areas in terms of heat mitigation and habitat for arthropod biodiversity. A secondary objective was to test three potential factors/indicators of LHGI performance: plant structure, plant diversity and the photograph derived complexity index. A tertiary objective was to evaluate the effects of mowing on arthropod biodiversity. To test the effect of potential simple vegetation intervention on those performance indicators, we used comparable recently implanted LHGI types to provide a semi-controlled sampling design in the Greater Montreal area.

2. Methods

2.1. Study area and sites

The study took place in the Greater Montreal area, which lies at the southern tip of the Province of Quebec, Canada (Fig. 1). The zone is characterized by a cool temperate climate with hot humid summers and cold snowy winters (Rizzo and Wiken, 1992) and corresponds to 6a Plant Hardiness Index of Canada (www.planthardiness.gc.ca). The study area was situated in a residential density zone of 30–100 dwellings per

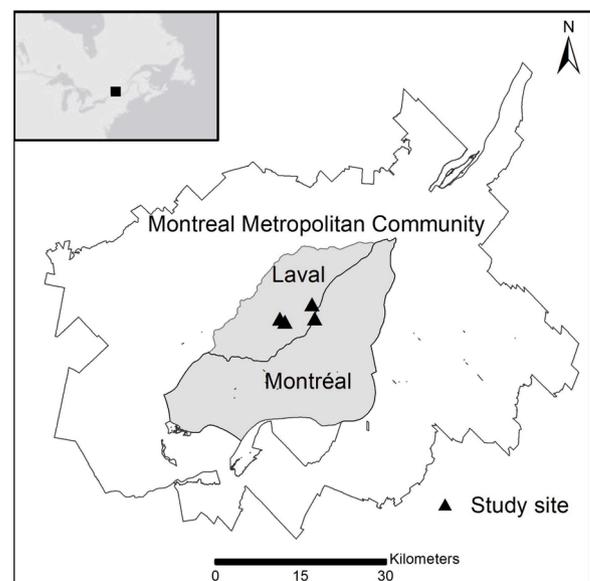


Fig. 1. Location of the study area in Quebec, Canada. The four triangles represent study sites in Laval and Montréal. See text for complete description.

hectare, which were suburbs close to city center. To assess the effect of vegetation intervention, study sites were selected from a list of recently implemented projects where lawn was complemented with other LHGI alternatives. These sites were designed by the environmental design firm Groupe Rousseau-Lefebvre who granted us research access. Among the sites that were established between 5 and 10 years prior to the study, four were selected based on their on-site availability of the four LHGI types to be compared. The choice of recently established sites was meant to capture the effects of short to mid terms effects of vegetation interventions. Those sites included: 1- The Clichy park (45.601906 °N, -73.663253 °W), 2- The Ile-de-la-Visitation Park (45.579676 °N, -73.657540 °W), 3- The Hydro-Quebec right-of-way north (45.579705 °N, -73.733311 °W), and 4- The Hydro-Quebec right-of-way East (45.576443 °N, -73.727106 °W). The LHGI types were chosen to contrast a gradient of plant structure and composition. This gradient consisted of i) unmanaged herbaceous vegetation (referred to here as flower meadow) planted from commercial flower meadow indigenous mix, ii) medium-sized hedgerow (hedgerow), iii) mowed regular lawn

(lawn), and iv) naturally regenerated shrub vegetation (natural) (See Fig. 2). The selection process was also meant to retain sites of similar aspect, composition and maintenance regime, which we assumed representative of LHGI habitats being established or maintained in the Greater Montreal context. The thorough selection process allowed the sampling design to tend to a semi controlled experimental design, as only the Natural type was not planted. For each site, 12 plots were located within a 50 m radius from a central point and at least 5 m apart. This close proximity of plots within a site was done to minimize the surrounding landscape effect (Garden et al., 2007, 2010). Each plot was two meters by two meters, delineated by four two-meter wooden stakes.

2.2. Variables

The response variables were characterized in each LHGI type by monitoring plot surface temperature, and arthropod species richness and biomass. Plot surface temperature was used as an indicator of the potential for a given LHGI to mitigate urban heat. Surface temperature

Unmanaged herbaceous vegetation (Flower Meadow)



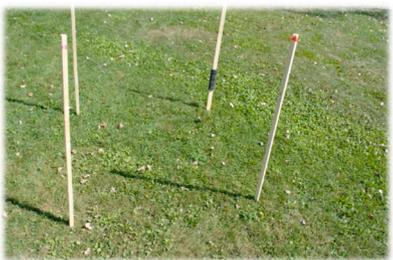
Plant Volume= $39.16 \pm 12.44 \cdot 10^{-1} \text{m}^3$
 Plant Richness= $10.33 \pm 2.90 \text{ sp.}$
 Plant Diversity= $3.75 \pm 0.78 \text{ sp.}$
 Maintenance: None

Mid-size hedgerow (Hedgerow)



Plant Volume= $83.74 \pm 29.78 \cdot 10^{-1} \text{m}^3$
 Plant Richness= $6.33 \pm 2.02 \text{ sp.}$
 Plant Diversity= $1.47 \pm 0.49 \text{ sp.}$
 Maintenance: none, mulched

Highly maintained lawn (Lawn)



Plant Volume= $6.83 \pm 2.44 \cdot 10^{-1} \text{m}^3$
 Plant Richness= $5.58 \pm 1.73 \text{ sp.}$
 Plant Diversity= $2.52 \pm 1.07 \text{ sp.}$
 Maintenance: mowed biweekly

Naturally occurring unmanaged shrub vegetation (Natural)



Plant Volume= $80.71 \pm 42.3 \cdot 10^{-1} \text{m}^3$
 Plant Richness= $9.92 \pm 3.15 \text{ sp.}$
 Plant Diversity= $3.98 \pm 1.46 \text{ sp.}$
 Maintenance: None

Fig. 2. The four low-height green infrastructure (LHGI) types compared in this study and their characteristics in terms of plant volume, plant richness, plant diversity and maintenance regime with associated standard deviation. We used three replicates of each LHGI type on the four study sites for a total of forty-eight plots. Plot dimensions were two by two meters and located within a fifty-meter radius from a central point to account for surrounding landscape effect. (For interpretation of the references to colour in the Figure, the reader is referred to the web version of this article).

was measured using infrared thermal imaging with the FlukeTi25 thermal imager (Fluke Corporation, Everett, USA). Using this device, the equivalent of 307 200 (resolution of 640 by 480 pixels) instant temperature readings of a plot can be simultaneously recorded. Thermal imagery was used rather than temperature data loggers (Armson et al., 2012) because of its spatial resolution and range, instant comparison among plots and ease of portability (see below). For each plot, we took an image at a 45° angle from a point precisely two meters high and away from the plot. For each image, we performed a calibration check by taking an image under a clear blue sky as it is a constant temperature. We took the thermal images on a hot, cloudless and windless, dry summer day, between 10am and 3 pm (see Table 1 in Appendices section for the camera settings). The maximum time interval for within-site thermal images was 50 min and we randomized the sampling sequence.

Arthropod diversity and biomass were used as indicators of the quality of each LHGI type as habitat for species and the ES they provide. Arthropod diversity was estimated via the morphospecies richness using the Rapid Assessment of Arthropods Diversity (RAAD) (Obrist and Duelli, 2010) methodology except that we modified the catching method from pitfall to standardized effort sweep netting. RAAD focuses on alpha diversity of arthropod morph classification rather than precise taxonomical identification, and is meant to produce temporal or spatial comparable data series at low cost and without the need of specialists in arthropod taxonomy. Though less thorough and precise than full taxonomical identification, there is a 92 % correlation between the RAAD approach results and full taxonomical identification (Obrist and Duelli, 2010). We chose to modify the catching approach to account for urban context constraints and to avoid depredation of the station based catching approach by dogs, raccoons, and humans (vandalism) for example. For each plot, five regular sweep motions were made which covered most of the plot vegetation. This procedure was repeated weekly for each plot from August 13th to September 15th, 2015 to obtain four sampling rounds during a valid window for arthropod survey. For a subset of our plots (6 out of 12), we sampled once before and three times after a mowing event so that we could quantify the effect of mowing (maintenance) on arthropod morphospecies richness and biomass. For each morph in each sample, we weighted the pooled individuals with an analytical scale (± 0.0001 g). With this data, we calculated arthropod morphospecies richness and aggregated biomass for each plot.

We first compared plot surface temperature, alpha diversity and

Table 1
Two dimensional photographs and thermal imagery camera settings.

Two dimensional photographs	
Camera lens	Nikon Digital SLR D3100
Camera lens	DX AF-S Nikkor 18–55 mm
Focal length	18 mm
Aperture diameter	6.3 mm
Focus distance	2 m
Tripod's head above ground	2 m
Depth of field (DF)	2 m - infinity
Exposure mode	Aperture priority
Time window for shooting	7h00–16h00
Visual obstruction < DF	Avoided
White balance mode	Direct sunlight
Resolution	4608 × 3072 pixels
Thermal imagery	
Camera	Fluke Ti25 Infrared Camera
Infrared lens type	20 mm F = 0.8 lens
Thermal sensitivity	≤ 0.1 °C
Infrared spectral bands	7.4 μ m to 14 μ m
Emissivity	97.5
Focus distance	2 m
Tripod's head above ground	2 m
Depth of field (DF)	2 m - infinity
Time window for shooting	10h00–15h00
Field of view	23° x 17°

biomass of arthropods among the four LHGI types investigated in this study. We then related them to the three explanatory variables we measured for each LHGI: plant structure, plant diversity and overall plot complexity as measured by an imagery technique. Three-dimensional plant structure was estimated through the use of the aggregated volume occupied by each plant species, i.e. area covered by each plant species within the four-square-meter plots multiplied by average measured height for those species, then combined for all species in a plot. Plant diversity was obtained by using the true diversity index (effective number of species), i.e. the exponential of Shannon diversity index (Jost, 2006), where we based the relative abundance on plant volume. The index of complexity was estimated by using the Mean Information Gain (MIG) for the brightness and hue components of plot images (Proulx and Parrott, 2009; Witté et al., 2013). The MIG is a measure of disorder in patterns in digital photographs based on Kolmogorov information complexity (Li and Vitányi, 1994). Using the pixels' values, the main idea of this measure is to quantify the length of the description needed to qualify the image. MIG values ranges from 0 to 1, where regular patterns present low values, and totally random patterns present high values. Since ecological complexity is thought to be a mix of regular and random patterns, highest complexity is found at an MIG of 0.5 (Proulx and Parrott, 2009). The same MIG calculation procedure as Witté et al. (2013) was used, but applied to an urban rather than forest context. Digital images were taken using a Nikon Digital SLR Camera D3100 (see Table 1 in Appendices section for camera settings) at a 45° downward angle from 2 m high and away. The MIG measures were computed with MATLAB version R2015B (2012b) using the same algorithm as Proulx and Parrott (2009), modified by Witté et al. (2013) (courtesy of Isabelle Witté). We then related the MIG for Brightness and Hue to each LHGI type and to our three measures of performance.

2.3. Data analyses

The comparison between LHGI types in terms of surface temperature, arthropod richness, and MIG index was estimated with linear mixed-effects model. The effects of plant structure and plant diversity on surface temperature, arthropod morphospecies richness, and MIG variables were also estimated with linear mixed-effects model. For the arthropod biomass response, we used a log normal distribution generalized linear mixed model. We used sites as random effect in all analyses to focus on local vegetation structure and diversity rather than particular site effect. We further assessed within types effects by nesting it into site as random effect. For linear mixed-effects models and generalized linear mixed models, we report the marginal and conditional R^2 as recommended by Nakagawa and Schielzeth (2013). The marginal R^2 describes the proportion of variance explained by the fixed factor(s) alone and the conditional R^2 describes the proportion of variance explained by both the fixed and random factors. To assess the effect of mowing on arthropod richness and biomass, we used linear mixed effects with weekly capture events as time variable. All tests were computed with the R 3.3.1 (2016–06-21) statistical programming language (R Development Core 2016). We used the packages MuMIn v.1.15.6, car v.2.1–2, MASS v.7.3–45 and nlme v.3.1–128.

3. Results

3.1. Comparing heat mitigation and arthropod morphospecies richness among LHGI types

Comparing metrics among the four LHGI types showed that lawn differed from the three other types showing statistically significant higher surface temperatures (Mixed effect model, $F = 7.14$ $df = 29$, $P = 0.001$, $R^2_m = 0.28$, $R^2_c = 0.55$) and lower statistically different arthropod biomass (Mixed effects model, $df = 40$, $P = 0.004$, $R^2_m = 0.33$, $R^2_c = 0.46$) (Fig. 3). The flower meadow type showed higher arthropod morphospecies richness compared to the other three LHGI

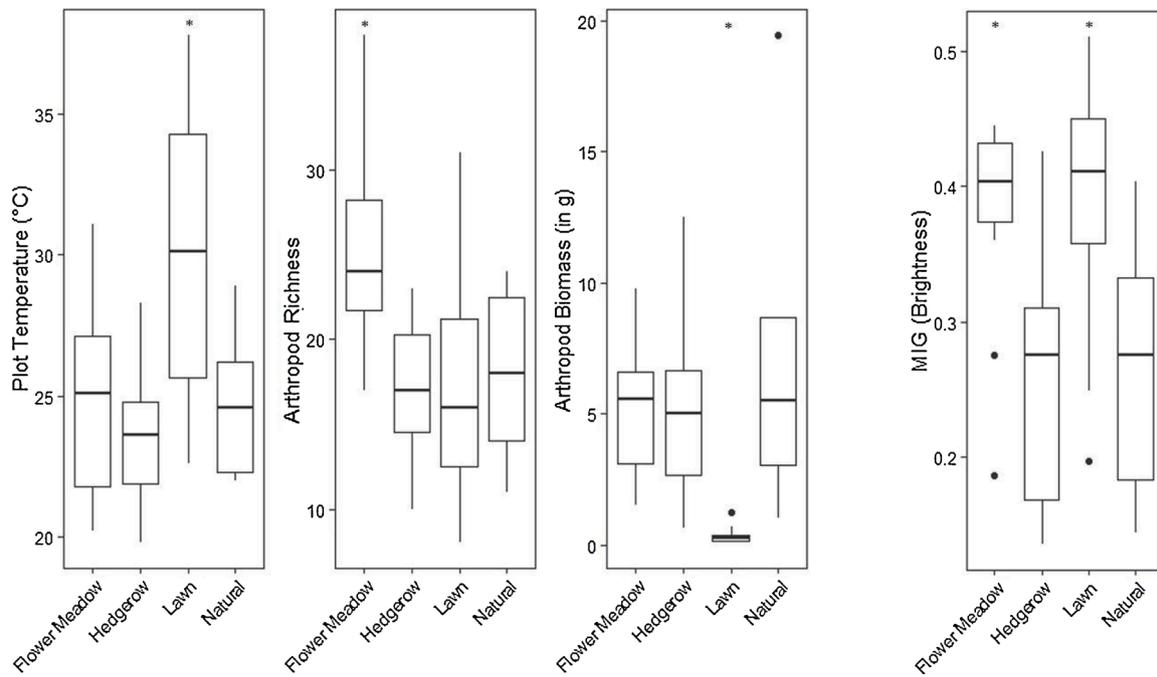


Fig. 3. Average plot surface temperature, arthropod morphospecies richness, arthropod biomass and Mean Information Gain (measure of plot complexity) comparison between lawns and other three alternatives of LHGI. Asterisk shows significant differences and dots represent outlying points for each LHGI type.

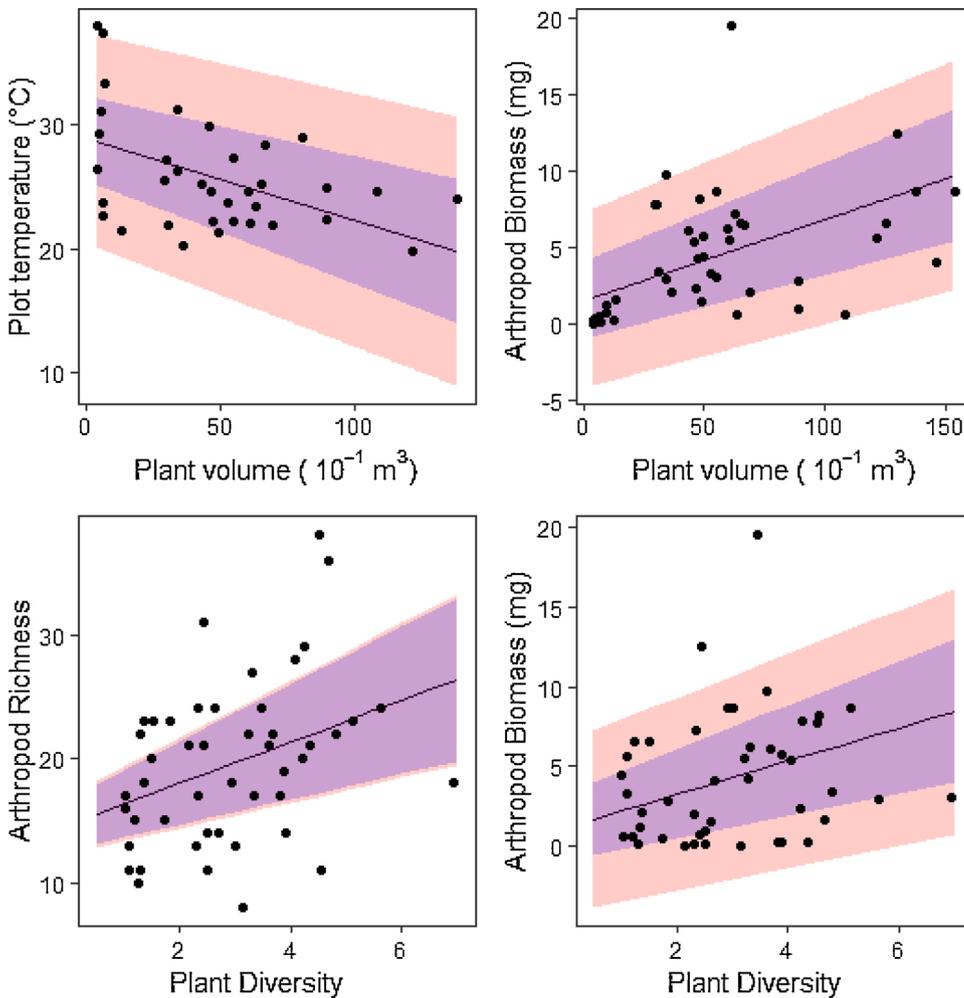


Fig. 4. Effect of plant volume (proxy for plant structure) and plant diversity (expressed in terms of effective number of species) on performance in terms of plot surface temperature, arthropod morphospecies richness, and arthropod biomass over 48 plots regardless of LHGI type. The pink area represents the mixed model standard deviation associated with random factor (study site) and the purple area represents model standard error of parameters. (For interpretation of the references to colour in the Figure, the reader is referred to the web version of this article).

types (Mixed effect model, $F = 6.55$, $df = 41$, $P = 0.001$, $R^2_m = 0.29$, $R^2_c = 0.29$).

Higher plant structure, estimated via plot plant volume, yielded lower plot surface temperatures (Linear mixed-effects model, $df = 31$, $F = 14.77$, $P = 0.0006$, $R^2_m = 0.22$, $R^2_c = 0.52$), and higher arthropod biomass (Generalized linear mixed model, $df = 31$, $T = 13.809$, $P < 0.0001$, $R^2_m = 0.18$, $R^2_c = 0.19$) (see Fig. 4). The plot surface temperature decreased by 1°C for every 1.53 m^3 increase of vegetation and plot arthropod biomass increased by 0.109 mg per m^3 of vegetation (Fig. 4). We further analyzed if the same effect could be found within each LHGI type, i.e. type nested in site as random effect, and we observed the same pattern as higher plant volumes decreased plot surface temperature (Linear mixed-effects model, $df = 21$, $T = 0.0204434$, $P = 0.048$, $R^2_m = 0.13$, $R^2_c = 0.72$) and slightly increased arthropod biomass (Linear mixed-effects model, $df = 30$, $T = 1.8263044$, $P = 0.009$, $R^2_m = 0.02$, $R^2_c = 0.06$) (Data not shown).

Higher plant diversity increased number of arthropod morphospecies by $1.46\text{ sp. per plant species increase}$ (Linear mixed-effects model fit by REML, $df = 42$, $T = 2.260797$, $P = 0.03$, $R^2_m = 0.15$, $R^2_c = 0.15$) (Fig. 4). Plant diversity also increased arthropod biomass by $0.25\text{ mg per plant species increase}$ (Linear mixed-effects model, $df = 42$, $T = 10.761$, $P < 2e-16$, $R^2_m = 0.17$, $R^2_c = 0.19$). Analysis within each LHGI type revealed no statistical difference. Plant diversity had no statistical impact on plot surface temperature.

3.2. Using mean information gain to compare LHGI types

The comparison of LHGI types based on the MIG-Brightness showed a highly significant difference of approximately 0.1 units between the natural and hedgerow types (approx. 0.3) and between the lawn and flower meadow types (approx. 0.4) (See Fig. 3) The analysis showed that 27 % of the variability in MIG-Brightness is explained by LHGI type and another 40 % by random effect due to site differences. Digging further, we found that MIG-Brightness slightly covaries with total plant volume (Linear mixed-effects model, estimate = -0.0013 unit per m^3 of vegetation, $df = 42$, $T = -5.30$, $P < 0.0001$, $R^2_m = 0.28$, $R^2_c = 0.58$). The analysis of MIG-Hue showed little variability between plots and no statistical difference were found among the LHGI types.

3.3. Effects of lawn maintenance

The effect of lawn maintenance on both arthropod morphospecies richness and biomass was significant (Fig. 5). When analyzing arthropod captures for six lawn plots over four weekly sampling events, we found that the effect of mowing reduced the arthropod morphospecies richness by half (Linear mixed-effects model, $df = 15$, $T = -7.19$, $P < 0.0001$, $R^2_m = 0.60$, $R^2_c = 0.82$) and greatly reduced arthropod biomass (Linear mixed-effects model, $df = 15$, $T = -2.30$, $P < 0.04$, $R^2_m = 0.24$, $R^2_c = 0.24$) (Fig. 5). Our results show that the numbers rise with time, but after a month, diversity and biomass had not returned to pre-mowing levels.

4. Discussion

The first objective was to compare lawn to three LHGI alternatives commonly implanted in the Greater Montreal area in regard of heat mitigation and habitat for arthropod diversity. Our results show a clear difference between lawn and the other three more structurally complex LHGI types as to surface temperature, arthropod morphospecies richness, and biomass. Lawn was hotter by almost 5°C on average (up to 14°C difference with neighboring LHGI plots in some cases). Similar to Armson et al. (2012) who found a notable difference in the cooling effect between grass and trees, our results show an increasing cooling effect with increasing structure of LHGI. This cooling effect is explained by the shading of solar radiation, and evapotranspiration (Dimoudi and Nikolopoulou, 2003; Lindén et al., 2016). Thus, an important cooling effect can be obtained by favoring more voluminous LHGI such as taller

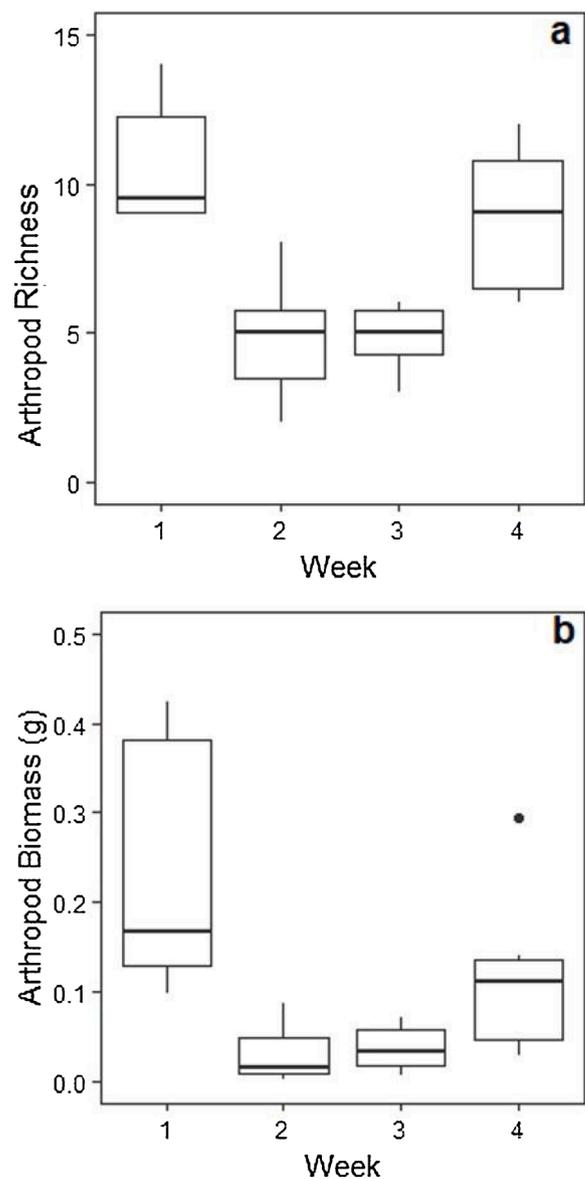


Fig. 5. Mean plot arthropod morphospecies richness (a) and biomass (b) in relation to time following a mowing event on a subset of six of the lawn plots. We had four arthropod sampling events per plot with the mowing event occurring at the end of week 1 (August 14th) in all plots.

herbaceous or shrub vegetation. Complexifying lawns thus represents an accessible and low-cost intervention to mitigate urban heat, especially in places where preference, physical or management constraints impede tree plantation. Lawn also harbors fewer arthropod morphospecies and biomass than surrounding more structurally complex LHGI types. The effect on arthropod biomass was noticeable as lawns harbored almost an order of magnitude less arthropod biomass, i.e. near zero, than other LHGI types investigated. This result resonates with the findings of Norton et al. (2019), which found that both diversity and abundance were higher in meadows compared to mowed lawn on a similar experiment in Southern England. Complexifying LHGI would support more organisms as well as a more complex trophic web, which is also supported by Lane (2016) and Schwartz et al. (2013). For example, more arthropod biomass could sustain a greater and more diverse bird community (Threlfall et al., 2016). A more complex community could also increase other ecosystems services (Cadotte et al., 2011; Schwarz et al., 2017) such as pollination (Garbuzov et al., 2015; Philpott et al., 2014), etc. However, more research is needed in this regard, notably on species

identity impact on such effects.

Regardless of LHGI types, the second objective was to assess the two main levers of intervention, i.e. plant structure and plant diversity. We found that plant structure, measured by plant volume, was a major factor affecting surface temperature and arthropod biomass. The importance of plant structure on ES has been shown before by [Sanusi et al. \(2017\)](#); [Cornelis and Hermy \(2004\)](#); [Norton et al. \(2019\)](#); [Smith et al. \(2006a\)](#) and [Smith et al. \(2006b\)](#) in urban environments, and our work confirms this finding for LHGI types. The noticeable change in plot surface temperature shows that for mitigating excess urban heat and related issues, complexifying plant structure yields strong effects even for a relatively small increase in plant structure such as moving from mowed grass to tallgrass to shrubs. The effects on arthropod biomass also suggest a possible influence on ecosystem functions through trophic availability of arthropods ([Faeth et al., 2005](#)). Moreover, we showed that plant diversity was an important contributing factor explaining arthropod diversity and biomass. This lever of intervention is also supported by [Chollet et al. \(2018\)](#) and [Norton et al. \(2019\)](#).

We tested whether we could effectively link a single indicator of habitat complexity, the Mean Information Gain index, to the LHGI environmental performances. We did find some differences in the MIG between the natural and hedgerow types and between the flower meadow and lawn, but could not successfully link MIG directly to any of the environmental performances measured in this study. The trends in our results, albeit promising, do not fully support the use of MIG as an overall indicator of environmental performance. Two factors may have limited our ability to properly test this new complexity index: the insufficient resolution of the image and an insufficient number of sampling plots. Similar limitations were reported in the study by [Witté et al. \(2013\)](#) in a natural forest context. The application of the MIG index to ecological phenomena is in its infancy and the methodology must be further refined and tested in multiple contexts to determine its potential. Furthermore, the calculation of MIG using regular photographs may be too simplistic or not representative of the true complexity found in vertically complex vegetation structure. Testing MIG on thermal imagery or on tridimensional imagery could yield better results and ought to be assessed. In our case, there is also the possibility that the MIG, a broad measure of complexity, could not relate to the few specific environmental performance measures we used, but would perhaps better relate to a broader quantification or aggregate of services produced by urban green infrastructures.

The third objective of this study was to evaluate the effects of lawn maintenance on arthropod biodiversity. We found that biweekly mowed lawn entails a two- to three-fold loss of arthropod morphospecies richness and an order of magnitude loss of arthropod biomass. Such a decrease is likely to be translated into diminished or vanished ES produced by mowed lawn ([Faeth et al., 2005](#); [Losey and Vaughan, 2006](#)). These results corroborate and expand on the findings of [Garbuzov et al. \(2015\)](#) on the mowing regime effects, adding a wider assessment of arthropod diversity and the effect on arthropod biomass. Our results also support the findings of [Norton et al. \(2019\)](#) which found that meadow alternative to lawn entailed positive biodiversity effects on arthropods. Even if our sample size was small, we found a strong and significant effect of mowing on lawn arthropod morphospecies richness and biomass. Reducing the mowing frequency from every week to every month or two could increase many key ES provided by this type of LHGI. This result concurs with the conclusions of [Politi Bertoncini et al. \(2012\)](#) who found that mowing frequency had a negative correlation with plant species richness and rarity, and affected lawn species composition. They also pointed out that frequently mowed lawns favor fewer species that tend to reproduce vegetatively, excluding most annual species and impeding plants to reach a reproductive state, e.g. flower and seed stages. These latter effects seem to be the main mechanism limiting arthropod diversity and biomass ([Garbuzov et al., 2015](#)).

However, this study's limitations, i.e. small sample size, limited number of habitats assessed and the use of the RAAD methodology,

impedes us to disentangle the species identity from the diversity effects on the LHGI production of ES. Even if biodiversity is likely to bring more numerous and more resilient ES production, species identity is of major concern since a few keystone species can radically modulate ES production ([Schwarz et al., 2017](#)). Such species identity effect can be pragmatically integrated in intervention planning through local horticultural knowledge or with tools like ([i-Tree Software Suite v6.1](#)) for woody species. However, this knowledge is limited for herbaceous species and species mix. The RAAD methodology is a low-cost effective method to assess arthropod biodiversity as to compare LHGI performances. However, this method proves difficult to be a precise indicator for invertebrate-related ES or for species of interest assessment. To address those challenges, future studies could use a hybrid method of RAAD and partial precisely targeted taxonomic assessment for ES providers such as key pollinator species, etc. This study locally measured two ES among many and thus represent a partial study of LHGI performances in the Greater Montreal context. Given the promising results, we suggest to replicate and broaden LHGI study to guide small scale vegetation interventions. Finally, as urban ES are mediated by non-ecological elements such as cultural and aesthetics aspects ([Kremer et al., 2016](#)), we suggest to study and integrate those aspects into intervention planning.

5. Conclusion

Our results show the limitations of lawn LHGI type as a contributor to heat mitigation and arthropod biodiversity in urban areas compared to the more voluminous and complex green infrastructure types, flower meadow hedgerow or shrub vegetation. Considering that lawn is one of the most abundant LHGI types in urban areas, the opportunity to improve the supply of ES in our cities is considerable. Simply letting lawn grow a few more centimeters was shown in this study to have a significant impact on arthropod richness, showing the potential impact of relatively minor modifications in the way we manage our lawn. Our study thus supports the idea that small vegetation intervention of LHGI can improve their performance ([Threlfall et al., 2017](#)).

Vegetation structure and plant diversity had complementary impacts in regard to heat mitigation and arthropod biodiversity. While vegetation structure, measured by volume, showed a linear relationship with heat mitigation, no such relationship was shown for plant diversity. However, in terms of arthropod biodiversity, both vegetation volume and plant diversity contributed positively. MIG using photographs did not show any link to heat mitigation and only a weak relation to arthropod biodiversity.

Our study suggests that complexifying oversimplified LHGI could increase ES provisioning, and that lawn, with its considerable extent in North America, is a low hanging fruit in this regard. Albeit the challenge posed by policies, cultural, aesthetics and other constraints, this study experimentally supports the ideas and conclusions of [Aronson et al. \(2017\)](#) which suggest that alternative management regimes in urban green infrastructures can be both more

CRediT authorship contribution statement

Xavier W. Francoeur: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization, Project administration. **Danielle Dagenais:** Conceptualization, Writing - review & editing, Supervision. **Alain Paquette:** Conceptualization, Writing - review & editing. **Jérôme Dupras:** Writing - review & editing. **Christian Messier:** Conceptualization, Writing - review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

the work reported in this paper.

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